Pilot-scale upgrading of landfill gas and sequestration of CO_2 by MSWI bottom ash

Peter Mostbauer[1], Tommaso Olivieri[2], Lidia Lombardi[2], Alessandro Paradisi[2]

[1]*Institute of Waste Management, University of Natural Resources and Life Sciences (BOKU), Vienna, AT*
[2]*Dipartimento di Energetica Sergio Stecco, Universita degli Studi di Firenze, Florence, IT*

Abstract – A process is described where bottom ash is used for upgrading of biogas / landfill gas and sequestration of CO_2 (BABIU process). Results from laboratory-scale testing of the BABIU process from 2007, 2008 and 2011 are summarized. In addition, the first results from the pilot-scale testing facility in Podere Rota (IT) are reported.

Keywords: Biogas upgrading, CO_2 sequestration, bottom ash.

INTRODUCTION

Upgrading of biogas/landfill gas (LFG) in combination with fixation/sequestration of CO_2 is a promising strategy to reduce greenhouse gas emissions in waste management and to produce a CH_4-containing fuel equivalent to natural gas. The most common biogas upgrading technologies applied today are: High Pressure Water Scrubbing (PWA, HPWS), pressure swing adsorption (PSA) and chemical scrubbing [#1]. Disadvantages of these processes are CH_4 losses, considerable consumption of electricity and release of CO_2 to the atmosphere.

In autumn of 2011, two demonstration scale gas processing installations were constructed at the landfill of Podere Rota (Italy) within the project UPGAS-LOWCO2 (www.upgas.eu). The aim of the UPGAS-LOWCO2 project is to demonstrate and evaluate innovative methods for upgrading of LFG or biogas, combined with the capture of CO_2. The project is co-funded by the European Commission in the frame of the LIFE+ programme.

In a former project (project "GHERL", 2006-2008), a demonstration plant was constructed at the Podere Rota landfill where CO_2 was captured by a packed column in the form of dissolved potassium carbonate (K_2CO_3 aq). The disadvantage of this absorption process was the previous consumption of potassium hydroxide (KOH). Newly constructed, additional devices enable the regeneration of the potassium carbonate solution by alkaline waste, for example APC residues. This so-called "alkali absorption-regeneration" process, which was developed in collaboration by the University of Florence (IT) and the Università di Roma Tor Vergata (IT), is described elsewhere [#2a, #2b]. The second process of which the technology is demonstrated within the UPGAS-LOWCO2 project is the BABIU process (**B**ottom **A**sh for **Bi**ogas **U**pgrading). The present paper describes the process, the BABIU pilot plant at Podere Rota and preliminary results.

BABIU PROCESS

With the BABIU process, CO_2 and H_2S are removed from LFG by solid-state reactions using moistened Municipal Solid Waste Incineration (MSWI) bottom ash (bottom ash quenched in water at the incineration plant) at atmospheric pressure [#3, #10]. Basic steps of the process are:

- Removal of coarse metals and storage/natural weathering of quenched bottom ash (or bottom ash fractions) for one to three weeks
- Filling one or several static containers ("carbonation tanks") with the weathered bottom ash
- Flushing with N_2 to remove air/O_2
- Reaction of biogas or landfill gas with the bottom ash, whereupon H_2S and CO_2 are fixed, $CaCO_3$ is formed and CH_4 is enriched in the product gas
- Second flushing with N_2 to increase CH_4 recovery and reduce CH_4 losses
- Removal of the treated bottom ash (with lower leachability) from the carbonation tank

Until December of 2011, results of test runs for the BABIU system were available at a laboratory scale (each test run: approx. 75 to 90 kg bottom ash) and for bottom ashes from Austria, Germany and Italy. In December of 2011, first test runs were conducted in Italy (Podere Rota) at a scale of 1 t bottom ash.

Reactions in bottom ash during weathering and carbonation

During combustion, CaO is formed by calcination of Ca-containing compounds in waste. As a result of quenching of the bottom ash (fast cooling in a water bath), CaO is hydrolyzed and forms $Ca(OH)_2$. Fine-grained $Ca(OH)_2$ is formed by this hydration reaction and dissolves partially in water. During natural weathering (ageing), the hydrated bottom ash takes up CO_2 slowly. With addition of CO_2, biogas, landfill gas or other CO_2-containing gases, the carbonation reaction is accelerated. It is believed that carbonation is a two-step reaction, consisting of CO_2 dissolution followed by neutralization [#4].

Hydration of CaO: $CaO + H_2O = Ca(OH)_2$, $\Delta H = -65$ kJ/mol

Partial dissolution of portlandite: $Ca(OH)_2 = Ca^{+2} + 2\ OH^-$

Carbonation: step 1) $CO_2 + H_2O = H_2CO_3$ step 2) $H_2CO_3 + Ca^{+2} + 2\ OH_2^- = CaCO_3 + 2\ H_2O$

Carbonation of other alkaline phases (simplified): $Na_2CaSiO_4 + H_2CO_3 = CaCO_3 + Na_2H_2SiO_4$

During slaking of lime, it was found that a thin layer of $Ca(OH)_2$ formed initially on the surface of CaO, impurities in the lime or a layer of $CaCO_3$ formed by carbonation may decrease the reaction rate of CaO hydration [#6, #7, #8]. It is not known to date if such a physical surface sealing effect occurs during hydration of bottom ash too. From the observation that bottom ash treated by accelerated carbonation indicates clearly alkaline reaction after grinding again, it is suggested that CaO may be present in the core of some grains even after “complete carbonation” of fresh bottom ash. In addition, it was observed in laboratory, that a somewhat higher CO_2 uptake (up to 15% more) compared to fresh bottom ash follows storage of bottom ash for a 6 to 21 days [#11]. Therefore, it is still recommended to store the moistened bottom ash for the industrial application of the BABIU process in large piles for one to three weeks. Aims of the storage in piles are complete hydration of CaO and prevention of excessive heat and hydrogen formation in the carbonation tanks during upgrading of biogas/landfill gas. Specifically, bottom ash where aluminum was not separated by eddy current technique may form amounts of H_2 that are not in line with feed-in standards. Figure 3 shows an example of the H_2 quantities formed by a bottom ash sample from Austria (plant S), which has been treated for metal recovery by magnets, but not with the eddy current technique. Further, one should take into account that the enthalpy of the Al oxidation reaction in alkaline media is quite large (415.6 kJ per mol Al, #5). Excessive heat formation could lead to temperatures beyond 70°C in the carbonation tanks, and thereby to higher evaporation of water. But water vapor has to be removed from the upgraded gas at least in case of feeding the gas to the grid.

Alkaline oxidation of Al [#9]: $Al + 2\ H_2O = AlOOH + 1.5\ H_2$

or, in case of excess of OH^-: $Al + OH^- + 3\ H_2O = Al[OH]_4^- + 1.5\ H_2$, $\Delta H = -415.6$ kJ/mol

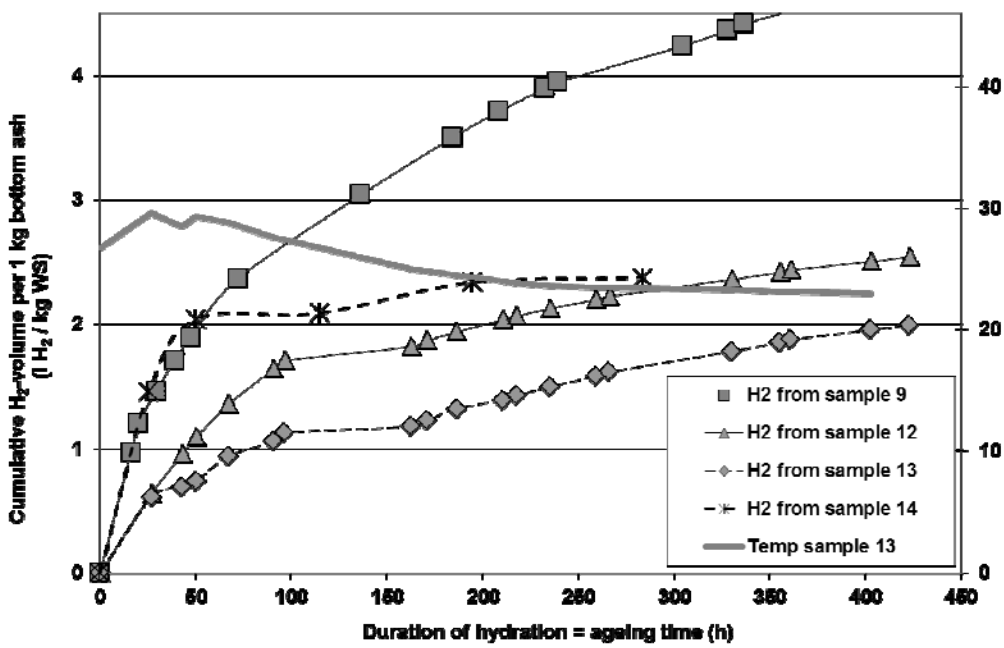

Figure 3: H_2 formation of four fresh bottom ash samples during storage

BABIU LABORATORY SCALE EXPERIMENTS

General

Laboratory scale experiments were performed at the Institute of Waste Management, BOKU within two previous projects [#11, #12] and recently within the project UPGAS-LOWCO2 (www.upgas.eu). Targets of the investigations were CO_2 fixation, treatment/stabilization of bottom ash, upgrading of biogas to grid quality or upgrading of biogas/landfill gas to prolong and facilitate utilization of the gas. In addition, four test runs (of, in total: 27) focused on H_2S removal. All experiments were conducted at atmospheric pressure and were designed to simulate an industrial-scale batch process as described below the heading "BABIU process".

Experimental

The equipment that has been applied in June of 2010 for upgrading of synthetic biogas with the use of bottom ash from Italy is shown in Fig 1. It is similar to the equipment which was used from April of 2006 on. The former version of the equipment has been reported elsewhere [#3].

The bottom ash was stored at room temperature and sieved to a specific grain size as reported in Table 1, and approx. 75 to 90 kg of the humid ash were used for each test run. The obtained bottom ash fraction was compacted in 3 layers in a gas-tight polyethylene reactor, the so-called "carbonation reactor", flushed with nitrogen and treated with synthetic gas (mostly: CH_4 + CO_2) immediately afterwards. The carbonation reactor was surrounded by thick styrofoam plates for thermal isolation and equipped with a calibrated thermometer.

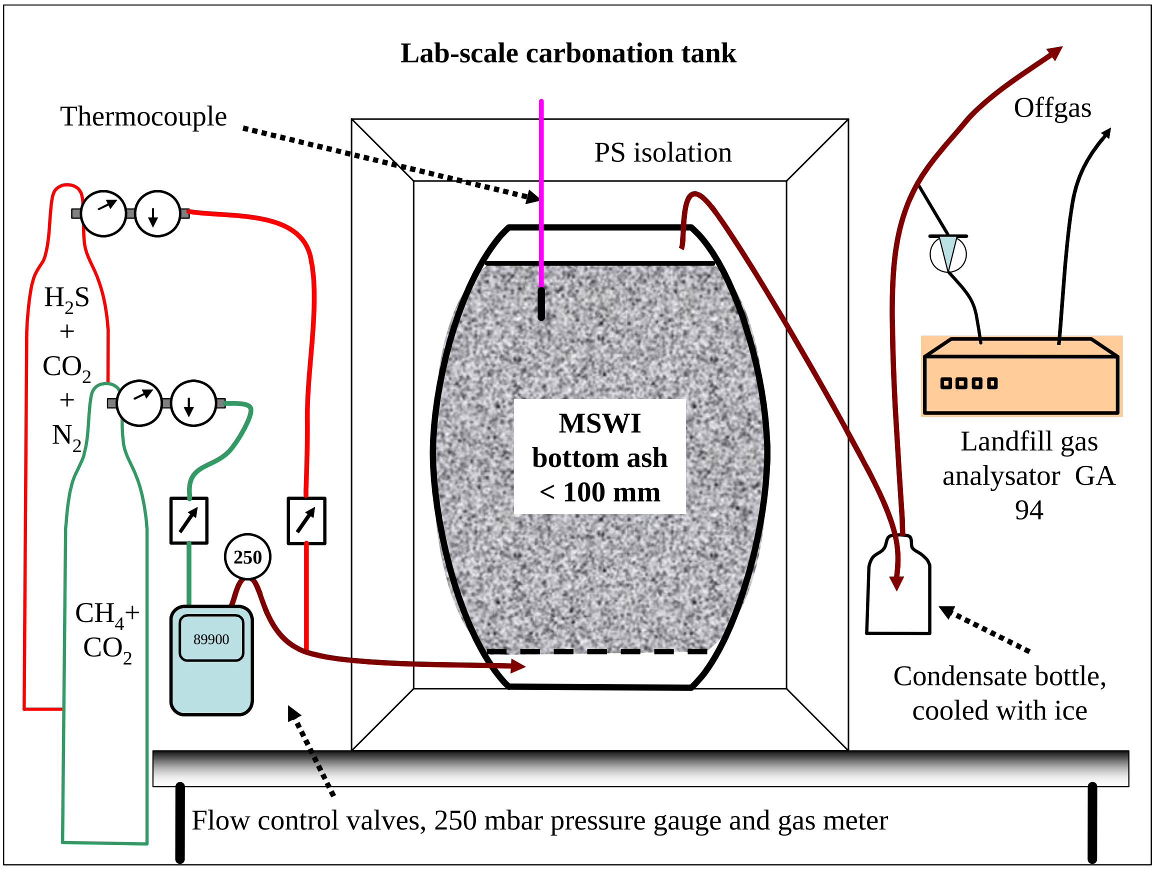

Figure 1: Experimental equipment for investigation of bottom ash from Italy, June 2010

Origin of ash (country / plant)	AT / plant S	AT / plant S	AT / plant F	GE / plant B	IT / plant A	IT / plant A	IT / plant A
Metal separation c)	magnetic	magnetic	none	magnetic + eddy c.	none	none	none
Grain size (mm)	< 20	< 20	< 20	0 - 11	< 100 d)	< 100 d)	< 100 d)
Storage/weathering time (d)	0 to 21	14	0 to 21	several weeks	8 (incl. time for transport to Austria)	10 (incl. time for transport to AT)	12 (incl. time for transport to AT)
Test run identifier	#4 LLFG tests	#4 LFG tests	#4 LLFG-F tests	#5 H_2S run 1,2,3,4	UPGAS Lab1	UPGAS Lab2	UPGAS Lab3
Initial temperature (°C)	depending on storage conditions: 23 to 40°C			21 to 26°C	23.1°C	25.4°C	27.0°C
Input gas composition	synthetic LLFG a)	61.0 to 65.6 Vol% CH_4, rest CO_2	synthetic LLFG a)	CO_2 + N_2 + H_2S	43.1 Vol% CO_2, 56.9 Vol% CH_4	43.1 Vol% CO_2, 56.9 Vol% CH_4	43.3 Vol% CO_2, 56.6 Vol% CH_4, 0.1 Vol% N_2, 237 ppm H_2S
Specific flow rate (m^3/h/t) b)	0.38 to 1.01	1.47 / 1.60	0,54 to 1.13	2.5 to 7.9	3.09 during the first two hours, then: 1.97	1.97	2.4

a) simulated lean landfill gas = mixture of CH_4 (mostly 24.8 Vol% CH_4, ranging from 16.5% to 40.4%) and CO_2

b) input gas volume at room temperature and ambient pressure (≈ 994 mbar) per hour and per ton of humid bottom ash

c) industrial scale separation of metals the bottom ash in the waste treatment installations

d) particles > 100 mm were separated by hand. The mass of large particles amounts to approx. 0.5% (mass%) of the total sample

Table 1: Experimental conditions of the laboratory scale experiments

Results from the laboratory scale experiments – bottom ash from Italy

The bottom ashes investigated so far indicate a similar behavior during the BABIU process. So as to warrant comparability with the pilot-scale test results only the results obtained with bottom ash from Italy were reported here in detail.

It has been demonstrated that the process performance is still excellent with an input flow rate of ≈ 2.0 to 3.0 m^3 synthetic landfill gas per hour and ton of bottom ash. As an example, the composition of the upgraded gas from experiment "UPGAS Lab 2" is shown in Figure 2. The dry product gas contained up to 99 Vol% of methane. The temperature increase observed in the laboratory test runs was 18 to 21°K. Using an estimation of the heat loss of the lab-scale carbonation tank, it is expected that the temperature increase in pilot scale and industrial scale will be in the range between 21 and 26°C in the case of the bottom ash from Italy.

The CO_2 fixation capacity of the bottom ash from Italy was 10.5 to 11.3 kgCO_2/tBA, which is rather low compared to bottom ash from Germany and Austria, where values up to 26 kgCO_2/tBA have been observed previously. Due to higher ratio of height to area, lower heat losses and expected higher tortuosity, the CO_2 uptake is expected to be somewhat higher at the industrial scale.

The H_2S fixation capacity of the bottom ash from Italy is sufficient for H_2S removal (37 g H_2S/t BA, experiment "UPGAS Lab 3"). The breakthrough time was more than 45 h at flow rate of 1.97 m^3/h/tBA (input gas) and with 237 ppm H_2S in input gas. In the lab-scale experiments the H_2S content of the raw gas was 237 ppm in average, whereas the H_2S content of the landfill gas ranges frequently from 10 to 1000 ppm. No breakthrough of H_2S is expected for the up-scaled BABIU process as long as the bottom ash reacts with CO_2. Additionally, the high H_2S fixation capacity leads to the suggestion, that bottom ash or alkaline bottom ash fractions from metal recovery could be used as a H_2S trap within a new process design, with a realistic potential to compete with conventional biological desulphurization processes.

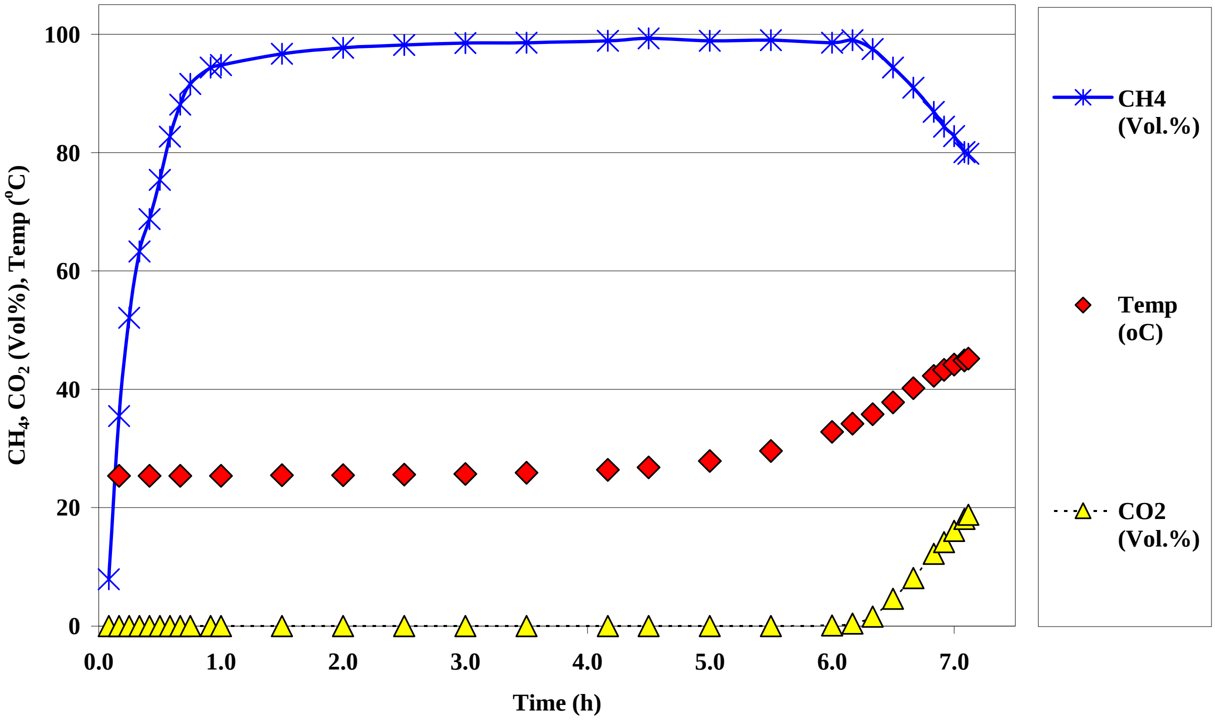

Figure 2: Experiment “UPGAS Lab 2”: CH_4 and CO_2 in upgraded gas, temperature of bottom ash.

Comparison of laboratory-scale results of different types of bottom ash

The most important process parameters for planning and technical evaluation of the full-scale upgrading process are: a) concentration and development of CH_4 in the upgraded gas b) the cumulative CO_2 uptake, c) the CO_2 breakthrough time d) the cumulative H_2S uptake, e) the H_2S breakthrough time and f) the maxima of observed temperature in bottom ash. In addition, concentrations of H_2 and siloxanes are of concern, but only a few data are available for H_2, and siloxanes were not measured to date.

In some of the previous experiments [#3, #10], the gas was recirculated by an additional pump. As it turned out that the gas recirculation led to early breakthrough of CO_2 and did not increase the process performance, only the test runs without gas recirculation were taken into account in table 2.

The dimension of the CO_2 uptake is kgCO_2/tWS (kg CO_2 fixed per t of humid bottom ash). The CO_2 uptake of bottom ash from plant “F” was 19.1 to 29.5 kg/tWS (with gas recirculation).

High CH_4 concentrations were reached frequently in the upgraded gas, but N_2 is not removed by the BABIU system. As a consequence, the ability to reach grid quality is limited specifically for lean landfill gas (gas with lower CH_4 and higher N_2/O_2 content).

The breakthrough of H_2S was always observed by far later than CO_2 breakthrough. Even carbonated bottom ash is capable to remove H_2S.

With the exception of admixtures of bottom ash and APC residues (APC sludge), the CO_2 uptake was in the range of 10.7 to 25.9 kgCO_2 per t of bottom ash (WS).

FTIR spectra of the treated bottom ash indicate fixation of CO_2 in the chemical form of calcite ($CaCO_3$). The leachability of Pb, Cu, Al, Zn and the pH value of the bottom ash eluates were clearly reduced [#10, confirmed again in 2011 with bottom ash from Italy].

Bottom ash origin and type	Plant S, fresh	Plant S, stored for 6 to 18 days in laboratory c)	Plant B, stored for several weeks in piles	Plant A, 8 to 16 days old
Grain size (mm)	< 20	< 20	0 -11	< 100
Country (origin)	AT	AT	GE	IT
CH_4 concentration maxima (Vol%)	91 - 98	91 – 99	n.d. e)	98 - 99
CO_2 uptake (kg/tWS)	10.7 – 21.5	15.7 – 25.9 a)	18.5 d)	10.5 – 11.3
CO_2 breakthrough (h)	10, 12, 43 b)	12 – 23 a)	approx. 3 e)	5.7, 6.3 f)
H_2S breakthrough (h)	> 19	> 48	> 180 e)	46
H_2S uptake (g/tWS)	n.d.	> 60	900	37 g)
Temp. maxima (^oC)	43.7 – 59.4	43.7 – 57.4 a)	approx.40 e)	43.3 – 45.2

a) With admixture of alkaline APC sludge: up to 39 kg/tWS, breakthrough time up to 40 h, temperature maxima up to 61.5^oC.

b) 43 h observed only in one test run at a very low input flow (0.38 l/kgWS/h).

c) Stored at room temperature in laboratory, covered with a liner or stored in a closed container which was equipped with a small glass siphon.

d) The number reported in the table refers to a fine fraction from upgrading of bottom ash for utilization as a landfill construction material. The CO_2 uptake of a 7 d old bottom ash sample from plant B was 12.2 kg/tWS. After treatment with a jaw crusher, it increased to 15.0 kg/tWS.

e) Input gas was 99.8% CO_2, 0.14% N_2 and 295 to 395 ppm H_2S, input flow rate 4.5 m^3/kgWS/h.

f) Data for test runs “UPGAS Lab1” and “UPGAS Lab2”.

g) From experiment “UPGAS Lab3”, obtained with H_2S-containing synthetic landfill gas.

Table 2: Overview on results from BABIU and H_2S removal laboratory scale experiments

BABIU PILOT PLANT AND PRELIMINARY RESULTS

Experimental installation and origin of the bottom ash

The BABIU pilot plant was constructed in 2011 at the Podere Rota landfill (Tuscany, Italy) by the Dipartimento di Energetica Sergio Stecco, Università degli Studi di Firenze, Florence (Figures 4a, 4b). The explosion-protected equipment was set up outdoor under roof to facilitate filling and discharge of bottom ash.

The ash used for test runs No. 1 and No. 2 was a conventionally quenched bottom ash from grate firing. Metals were not separated at all for test run No.1 and separated as described below for run No.2. A sample of approximately 3.5 ton was taken on 08/12/2011 directly from the bunker of the Arezzo incineration plant (IT). After separation of coarse metal particles, the water content of the sample was approximately 22% (mass).

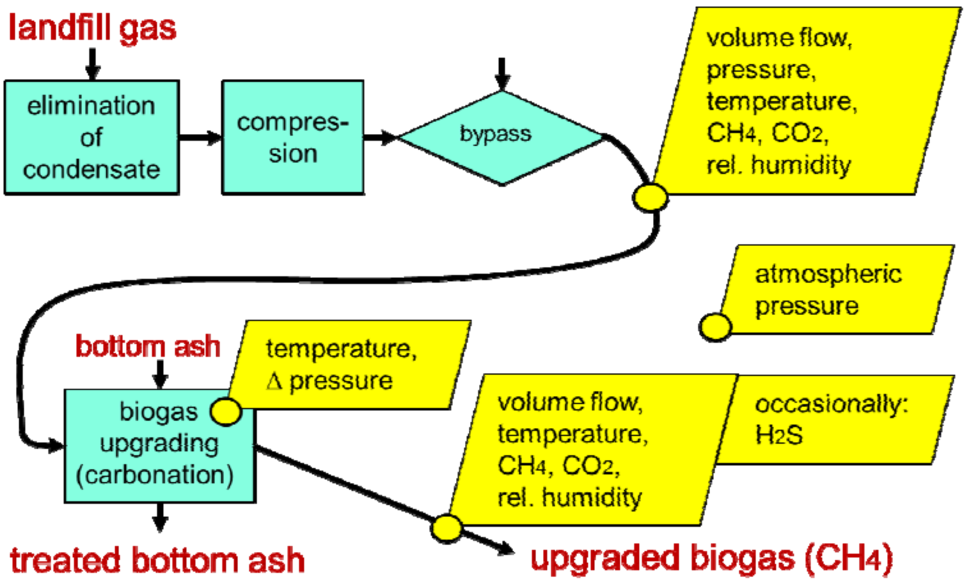

Figure 4a: Podere Rota pilot plant, BABIU process.

Figure 4b: The Podere Rota pilot plant.

Explanation of figures 4a, 4b:

a) Circles in the drawing indicate the location of the probes and the measured parameters

b) Photo (from left to right): compressor with centrifugal condensate separator, small metal cylinder for input pressure and temperature probes, input gas analyzer, propeller flowmeter (small blue box), carbonation tank 1, second small metal cylinder, carbonation tank 2 with output gas analyzer on top, second propeller flowmeter, nitrogen gas bottle (50 l).

c) Computer controlling - not shown in the photo – this equipment was installed indoor aside the plant.

The main purpose of the pilot plant is demonstration and evaluation of the BABIU process at a larger scale. The BABIU carbonation tanks are supplied with real landfill gas from the Podere Rota landfill and designed to contain about one ton of bottom ash.

Results – Test run No.1

Test run No.1 of the pilot plant was conducted on 13/12/2011 with 1.04 tons of bottom ash from the Arezzo waste incineration plant. The bottom ash was stored for four days under a plastic liner and one day within the carbonation tanks. After flushing with N_2, landfill gas from the Podere Rota landfill was fed to the first carbonation tank, and the gas obtained in tank 1 was fed to tank 2 (see Fig.4).

The flow rate for initial flushing with nitrogen was 4.8 m^3N_2/h. The O_2 content of the flushing gas from tank 1 and tank 2 was observed in regular intervals (5 min). After 15 minutes, O_2 was below 0.2 Vol% in both of these gases. From this observation (and from similar data obtained in test run No.2) it was concluded that the N_2 demand for initial flushing will be approx. 0.8 m^3 N_2 per ton of bottom ash for a full-scale industrial application.

After flushing, the tanks were fed with real landfill gas from Podere Rota. The average flow rate of the input gas was approximately 2 m^3/h. The CH_4 concentration in the upgraded gas peaked in 84.5 Vol% - a quite low maximum compared to Table 2, which was attributed to the presence of coarse metal particles (up to approx. 30 cm length) in the bottom ash, which caused some “channeling” (preferential flow paths) during test run No.1.

Unfortunately, heavy rainfall at the landfill site on 13/12/2011 caused flooding of the gas well. As a consequence, the compressor received air and an explosive gas/air mixture was pumped into tank 1. As soon as this alarming situation was discovered, the whole system was flushed with N_2 and the experiment had to be terminated. The lesson learned therefrom is that an industrial-scale BABIU application on a landfill requires the same safety precaution as other gas utilization installations, most notably permanent O_2 measurement, alarm systems and automatic shut-down in case of air access.

In the first part of Test run No. 1 a temperature increase in the first reactor was observed with an average increment with respect to the entering temperature of 3.8°C, while the average temperature in the second reactor was only 1.2°C higher than in the first one. In the second part of Test run No. 1 the temperature increase in the first reactor was very low (average 1.3°C), while carbonation of the second reactor started, with an average increase of temperature from the first reactor to the second one of about 6.6°C.

From each of the carbonation tanks, solid samples were taken during discharge of the treated bottom ash. The pH of the bottom ash, observed in the L/S=2 extract, dropped down from 12.2 to 10.6 in carbonation tank 1. Contrary, the sample from tank 2 was only partially carbonated (pH 12.1) in test run No.1.

Results – Test run No.2

For test run No.2 (16/12/2011), the coarse metal particles were removed from the intermediately stored bottom ash from the Arezzo waste incineration plant. The mass of the bottom ash was 1.0 ton. The total storage time of the bottom ash was 8 days. As the bottom ash has been stored in a thin layer (and as nights are cold in December even in Italy) the ash cooled down to approx. 8 to 12^{o}C before it was fed to the carbonation tanks.

Test run No.2 was conducted with an average gas flow rate of 3.0 m^3/h/tWS. No early breakthrough of CO_2 occurred in spite of this rather high flow rate (high compared to previous laboratory test runs). The CH_4 content in the upgraded gas reached 97 Vol% (Fig.4). It is expected that the remaining 3% consist of nitrogen mainly, which cannot be avoided completely during suctioning of landfill gas, and some H_2.

During Test run No. 2, the first reactor temperature increased continuously up to 20,3°C more than the entering temperature (to a maximum of 34.0°C after 6 hours and 40 minutes), with an average increase of about 8.9°C. The temperature of the second reactor (measured on top in the upgraded gas) started to increase only after five hours and twenty minutes.

No breakthrough of H_2S was observed in both of the test runs. Even the offgas from tank 1 did not contain H_2S (<2 ppm). The H_2S content of the landfill gas (input gas) ranged from 38 to 90 ppm.

The total duration of the experiment (without time of preparatory works but with 20 min of initial flushing with N_2 and 15 min of final flushing with N_2) was 7.25 hours. The total gas volume pumped into the carbonation tank No.1 in test run No.2 was 20.1 m^3 of landfill gas. The CO_2 uptake of the bottom ash was 14.6 $kgCO_2$/tWS.

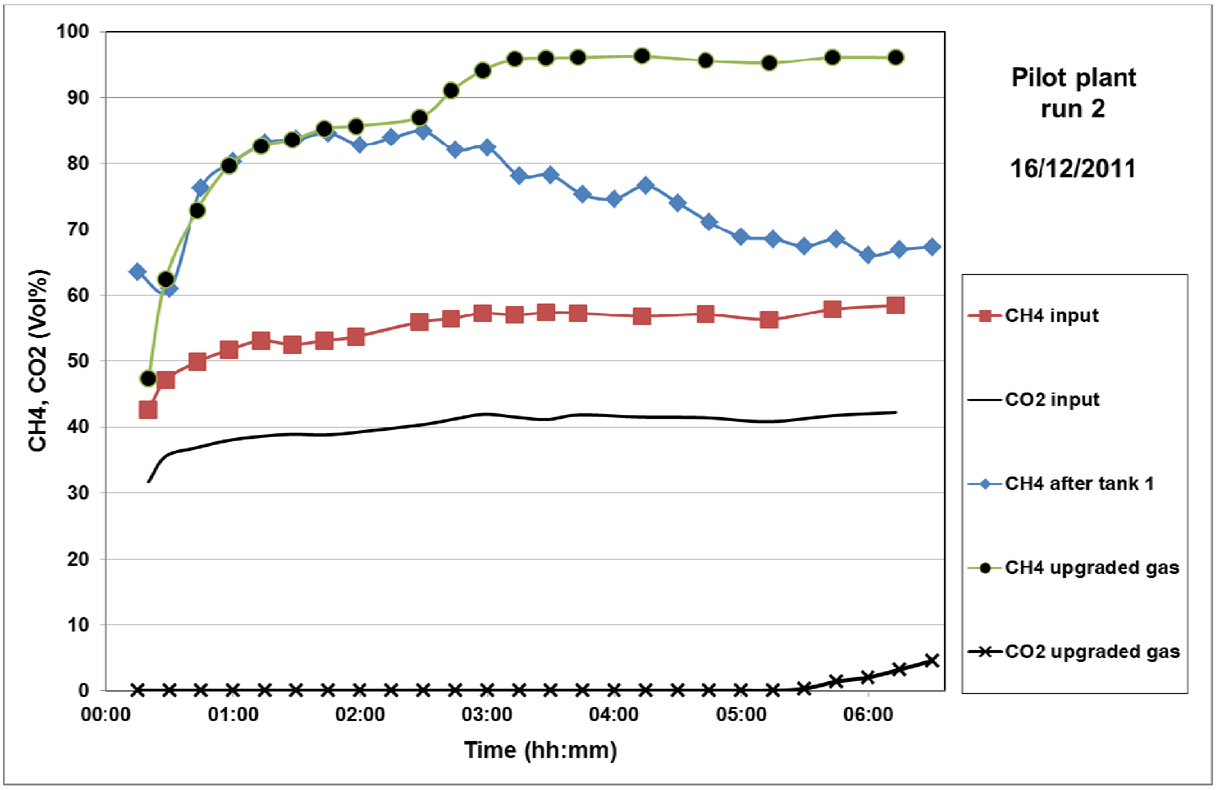

Figure 5: Pilot-scale test run No.2: CH_4, CO_2.

Discussion of potential industrial applications

From the data obtained in laboratory and the preliminary results of the pilot plant test runs, and taking into account the costs of competing technologies for upgrading of biogas and the natural gas market as well, we recommend to perform a closer environmental and economic evaluation of the following potential industrial applications:

- Upgrading of lean landfill gas (landfill gas low in methane, for example < 35% CH_4) to prolong the use of conventional gas utilization in reciprocating engines, micro-turbines etc.
- Protection of utilization units (especially: reciprocating engines) from H_2S corrosion by elimination of H_2S from biogas or landfill gas.
- Upgrading of biogas with a low content of N_2 and low siloxanes content (e.g. digester biogas, biogas from sewage sludge treatment) to generate a high-calorific gas ("H-gas") for grid injection.
- Upgrading of "normal" landfill gas (not lean landfill gas) to generate a medium-calorific gas ("L-gas") in regions where natural L-gas is distributed.
- Downgrading of natural H-gas to L-gas by admixture of upgraded gas from the BABIU process. The conversion of H-gas to L-gas is presently achieved in the Netherlands by admixture of nitrogen [#6], but the N_2 conversion process is associated with economic and environmental burdens.
- Use of the BABIU process for primary scope of fast ageing/stabilization (accelerated carbonation) of bottom ash associated with conventional combined utilization of biogas/landfill gas and upgraded biogas/upgraded landfill gas.

Due to permanent fixation of CO_2 and a rather low consumption of energy, the CO_2 balance of the BABIU system is auspicious [#13]. Particularly in the presence of low bottom ash transport distances the BABIU process was shown [#14] to be increasingly environmentally-friendly compared to scenarios in which other upgrading methods are applied. The results from pilot-scale test run No.2 and further pilot test runs within the project UPGAS-LOWCO2, which will be conducted in spring of 2012, provide additional data for CO_2-balances of some of the scenarios mentioned above, for example a better estimation of energy consumption of the BABIU process and a more precise prediction of the N_2 demand at an industrial scale.

With respect to standards for feeding gas into the grid in H-gas regions, for example the Austrian guidelines [#15] regulating the injection into the Austrian natural gas grid, the upgraded gas from the Podere Rota pilot plant was not high enough in CH_4 and calorific value. Therefore, interchangeability of natural gas of high calorific value ("H-gas" quality) and upgraded gas from the BABIU process is not provided. Contrary, natural gas of lower calorific value ("L-gas") is distributed in several natural gas networks in northern France, Belgium, Netherlands and the north-western part of Germany [#16]. Even in case that the biogas or landfill gas contains some nitrogen (up to approx. 5% N_2), upgrading to L-gas grid quality is feasible.

The use of bottom ash with the primary intention to reduce H_2S in raw biogas/landfill is an interesting version of the BABIU process. With a high content of H_2S and siloxanes in crude landfill gas, reciprocating engines need frequent and costly maintenance. Further tests have to be conducted to complete the technical and economic evaluation of the BABIU process with regard to removal of H_2S.

Finally, the BABIU process could be conceived as a treatment process for fast stabilization (accelerated carbonation) of bottom ash. The economic value of such a bottom ash recycling scenario depends strongly on the market for gravel and gravel substitutes, the metal markets and standards applied to secondary construction material. In any case, the CH_4-enriched gas generated as a "by-product" within this strategy should not be emitted, but utilized or (less environmentally justifiable, but still feasible) flared.

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